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Air Force Space Command

**SPACE AND MISSILE SYSTEMS CENTER
STANDARD**

**SOLID ROCKET MOTOR
CASE DESIGN AND TEST**

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FOREWORD

1. This standard defines the Government's requirements and expectations for contractor performance in defense system acquisitions and technology developments.
2. This new-issue SMC standard comprises the text of The Aerospace Corporation report number TOR-2003(8583)-2895, Rev 1.
3. Beneficial comments (recommendations, changes, additions, deletions, etc.) and any pertinent data that may be of use in improving this standard should be forwarded to the following addressee using the Standardization Document Improvement Proposal appearing at the end of this document or by letter:

Division Chief, SMC/EAE
SPACE AND MISSILE SYSTEMS CENTER
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245

4. This standard has been approved for use on all Space and Missile Systems Center/Air Force Program Executive Office - Space development, acquisition, and sustainment contracts.



James Horejsi, Col, USAF
SMC Chief Engineer

Contents

| | |
|---|----|
| 1. Introduction | 1 |
| 1.1 Scope | 1 |
| 1.2 Application | 1 |
| 2. Reference Documents | 3 |
| 3. Vocabulary | 5 |
| 3.1 Definition | 5 |
| 3.2 Abbreviations and Acronyms | 8 |
| 4. General Requirements | 9 |
| 4.1 General Design and Analysis | 9 |
| 4.1.1 System Analysis | 9 |
| 4.1.2 Loads, Pressures and Environments | 9 |
| 4.1.3 Strength | 9 |
| 4.1.4 Field Joint Sealing | 10 |
| 4.1.5 Stiffness | 10 |
| 4.1.6 Thermal Effects | 10 |
| 4.1.7 Structural Analysis | 10 |
| 4.1.7.1 Stress Analysis | 10 |
| 4.1.7.2 Field Joint Deformation Analysis | 11 |
| 4.1.8 Damage Tolerance (Safe-Life) | 11 |
| 4.1.9 Impact Damage Control | 11 |
| 4.1.9.1 Impact Damage Control Plan | 11 |
| 4.1.9.2 Approach A: Impact Damage Protection/Indication | 11 |
| 4.1.9.2.1 Protective Covers | 11 |
| 4.1.9.2.2 Indicators | 11 |
| 4.1.9.3 Approach B: Impact Damage Tolerance Demonstration | 12 |
| 4.1.10 Stress-Rupture Life | 12 |
| 4.2 Materials | 12 |
| 4.2.1 Metallic Materials | 12 |
| 4.2.1.1 Metallic Material Selection | 12 |
| 4.2.1.2 Metallic Material Evaluation | 12 |
| 4.2.1.3 Metallic Material Characterization | 12 |

| | | |
|------------------|---|----|
| 4.2.1.4 | Metallic Material Strength Allowables | 13 |
| 4.2.2 | Composite Materials | 13 |
| 4.2.2.1 | Composite Material Selection | 13 |
| 4.2.2.2 | Composite Material Evaluation | 13 |
| 4.2.2.3 | Composite Material Characterization | 14 |
| 4.2.2.4 | Composite Material Strength Allowables | 14 |
| 4.3 | Fabrication and Process Control | 14 |
| 4.3.1 | Metal Parts Fabrication and Process Control | 14 |
| 4.3.2 | Composite Parts Fabrication and Process Control | 14 |
| 4.4 | Quality Assurance | 15 |
| 4.4.1 | Inspection Plan | 15 |
| 4.4.1.1 | Inspection Techniques | 15 |
| 4.4.1.2 | Inspection Data | 15 |
| 4.4.2 | Acceptance Test | 15 |
| 4.4.2.1 | NDE | 16 |
| 4.4.2.2 | Hydro-Proof Test | 16 |
| 4.4.2.3 | Leak Check | 16 |
| 4.5 | Repair and Refurbishment | 16 |
| 4.6 | Storage | 17 |
| 4.7 | Transportation | 17 |
| 5. | Design Verification Requirements | 19 |
| 5.1 | Margin of Safety (MS) | 19 |
| 5.2 | Damage Tolerance (Safe-Life) Demonstration | 19 |
| 5.2.1 | Damage Tolerance (Safe-Life) Analysis | 20 |
| 5.2.2 | Damage Tolerance (Safe-Life) Test | 20 |
| 5.3 | Impact Damage Tolerance Demonstration | 20 |
| 5.4 | Qualification Test | 20 |
| 5.4.1 | Pressure Cycle Test | 21 |
| 5.4.2 | Burst Test | 21 |
| Table 5-1 | Qualification Test Pressure Cycle Requirements | 21 |

1. INTRODUCTION

1.1 Scope

This standard establishes baseline requirements for the design, fabrication, qualification and acceptance tests, and inspections of the solid rocket motor cases (SRMCs) of launch vehicles. An SRMC consists of the outer shell and the associated factory and field joints. The associated aft skirt, nose cone, and other structural components are not included. Solid propellants, insulators and other nonstructural components, such as O-rings, are also not included.

1.2 Application

This standard is applicable only to the SRMCs used in expendable launch vehicles (ELVs). SRMCs used in missiles and other weapon systems are not considered herein.

The requirements specified in this standard may be tailored to specific programs with the agreement of the appropriate contractual authority.

2. REFERENCE DOCUMENTS

The latest issues of the following documents are referenced for establishing designs, analyses, demonstrations, and tests for SRMCs.

MIL-HDBK -5, *Metallic Materials and Elements for Aerospace Vehicle Structures*, two volumes

MIL-HDBK-17, *Polymer Matrix Composites*, five volumes

NASA Standard, NASA-STD-5003, *Fracture Control Requirements for Payloads Using the Space Shuttle*

Aerospace Structural Metals Handbook

Damage Tolerance Design Handbook

Aerospace Technical Operating Report (TOR) 2003(8583)-2894, *Space Systems-Structures Design and Test Requirements*

ANSI/AIAA Standard S-080-1998, *Space-Systems- Metallic Pressure Vessels, Pressurized Structures, and Pressure Components*

ASTM E647, Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials

ASTM E399, Standard Test Method for Measurement of Fatigue Crack Growth Rates

ASTM E1681, Standard Test Method for Determining a Threshold Stress Intensity Factor for Environment-assisted Cracking of Metallic Materials

3. VOCABULARY

3.1 Definition

The following definitions of significant terms are provided to ensure precision of meaning and consistency of usage. In the event of a conflict, the definitions listed below take precedence:

"A" Basis Allowable: The mechanical strength value above which at least 99% of the population of the values is expected to fall, with a 95% confidence level.

Acceptance Test: The required formal test conducted on a flight SRMC to verify that the materials, manufacturing processes, and workmanship meet specifications and that the SRMC is acceptable for its intended usage.

Allowable Load (Stress/Strain): The maximum load (stress/strain) that can be accommodated by the SRMC without rupture, collapse, or detrimental deformation in a given environment.

Applied Load (Stress): The actual load (stress) imposed on the SRMC in the service environment.

"B" Basis Allowable: The mechanical strength value above which at least 90% of the population of the values is expected to fall, with a 95% confidence level.

Brittle Fracture: A type of catastrophic failure mode in structural materials that usually occurs without prior plastic deformation and at extremely high speed. The fracture is usually characterized by a flat fracture surface with little or no shear lips (slant fracture surface) and at average stress levels below those of general yielding.

Burst Pressure: The pressure level at which rupture or unstable fracture of the SRMC actually occurs.

Case: The major structural component of a solid rocket motor (SRM) that carries primarily the external load and internal pressure. In this standard, only the outer shells and their associated factory and field joints are referred to as an SRMC.

Composite Solid Rocket Motor Case (CSRMC): An SRMC made of composite materials, either by filament winding or other manufacturing processes.

Critical Environment: The most severe environmental condition in terms of loads, pressures, and temperatures, or combinations thereof, imposed during SRMC service life.

Critical Flaw: A specific shape of a flaw or a crack-like defect existing in the metallic components of an SRMC with sufficient size that unstable growth will occur under the specified operating load and environment.

Damage Tolerance: The ability of the SRMC to resist failure due to the presence of flaws, cracks, delaminations, impact damage, or other mechanical damage.

Design Burst Factor (DBF): A multiplying factor to be applied to maximum expected operating pressure (MEOP) to obtain design burst pressure for the purposes of analytical assessment and/or test verification of the strength adequacy of the SRMC design.

Design Burst Pressure: A pressure level that the SRMC must withstand without rupture in the applicable operating environment. It is equal to DBF x MEOP.

Design Safety Factor (DSF): A factor by which limit loads, including MEOP, are multiplied in order to account for the statistical variation of structural resistance and inaccuracies in structural analysis and manufacturing processes. Design safety factor is often called design factor of safety, or, simply, factor of safety.

Destabilizing Pressure: A pressure that produces compressive stresses in the SRMC.

Detrimental Deformation: Structural deformation, deflection, or displacement that prevents any portion of the SRMC from performing its intended function, or that reduces the probability of successful completion of the mission.

Development Test Program: A test program conducted to provide design information that may be used to check the validity of analytic techniques and assumed design parameters; to uncover unexpected system response characteristics; to evaluate design options; to determine interface compatibility; to prove qualification and acceptance procedures and techniques; and to establish accept/reject criteria for nondestructive evaluation (NDE).

Embrittlement Mechanism: A failure process that results from the interaction of environments with metals, usually in combination with applied or residual tensile stresses. The most common type of such failure process is hydrogen embrittlement, caused by an initial presence or absorption of excessive amounts of hydrogen in metals.

Flaw Shape (a/2c or a/c): The shape of a part-through crack. For a surface flaw, the flaw shape is identified as **a/2c** where **a** is the depth and **2c** is the length of the surface flaw. The term **a/2c** is also referred to as the aspect ratio. For a corner crack at the edge of a hole, the flaw shape is identified as **a/c** where **a** is the depth and **c** is the length of the corner crack.

Fracture Control: The application of design philosophy, analysis method, manufacturing technology, quality assurance, and operating procedures intended to prevent premature structural failure of metal components due to the propagation of cracks or crack-like defects during fabrication, testing, transportation and handling, and service.

Fracture Mechanics: An engineering discipline that describes the behavior of cracks or crack-like defects in materials under stresses.

Fracture Toughness: A generic term for the quantitative measurement of the resistance to extension of a crack in metals.

Hydro-Proof Test: An acceptance proof test that uses water to pressurize SRMCs.

Impact Damage: Mechanical damage caused when an object strikes a CSRM or vice versa.

Impact Damage Control: Processes and procedures intended to protect a CSRM from damage due to potential impact events in the manufacturing, testing, transportation, ground handling, storage, assembly and service stages.

Initial Flaw: A crack or a crack-like defect in metallic parts of an SRMC before the application of load/pressure and deleterious environment.

Limit Load: The maximum expected external load and aerodynamic pressure or combination of loads that an SRMC may experience during the performance of specified missions in specified environments. When a statistical estimate is applicable, the limit load is that load not expected to be exceeded at 99% probability with 95% confidence. The corresponding stress is called limit stress.

Margin of Safety (MS):

$$MS = [\text{Allowable Load}/(\text{Ultimate load})] - 1$$

Note: Load may mean stress or strain, force or pressure

Maximum Expected Operating Pressure (MEOP): The maximum pressure an SRMC is expected to experience during its service life.

Proof Factor: A multiplying factor applied to the limit load and/or MEOP to obtain proof load and/or proof pressure for use in acceptance testing.

Proof Pressure: Application of proof pressure is used to demonstrate satisfactory workmanship and material quality. It is equal to the product of MEOP and the proof factor.

Qualification Tests: The required formal contractual tests used to demonstrate that the design, manufacturing, and assembly have resulted in an SRMC conforming to specification requirements.

Residual Strength: The maximum pressure/load that a cracked or damaged structural component is capable of sustaining without rupture.

Stress-Corrosion Cracking: A mechanical-environmental induced failure process in which sustained tensile stress and chemical attack combine to initiate and propagate a crack or a crack-like flaw in a metallic component of the SRMC.

Stress Intensity Factor (K): A parameter that characterizes the stress-strain behavior at the tip of a crack contained in a linear elastic, homogeneous, and isotropic body. The value of the stress intensity factor at which unstable fracture occurs is referred to as the critical stress intensity factor, or the fracture toughness.

Stress Rupture Life: The minimum time during which a CSRM maintains structural integrity during its required service life considering the combined effects of stress level(s), time at stress level(s), and associated temperature and moisture conditions.

Ultimate Load: The product of the limit load and the ultimate design safety factor.

Visual Damage Threshold: (VDT): An impact energy level shown by test(s) that creates an indication on a CSRM's surface that is barely detectable by unaided visual inspection.

3.2 Abbreviations and Acronyms

| | |
|------------|---|
| AIAA | American Institute of Aeronautics and Astronautics |
| ANSI | American National Standards Institute |
| ASTM | American Society for Testing and Materials |
| BF | Burst Factor |
| CSRMC | Composite Solid Rocket Motor Case |
| Da/dN | Fatigue crack growth rate |
| DBF | Design Burst Factor |
| DSF | Design Safety Factor |
| ELV | Expendable Launch Vehicle |
| F_{tu} | Ultimate tensile strength |
| HDBK | Handbook |
| IAT | Individual Acceptance Test |
| K_{lc} | Plane strain fracture toughness |
| K_{le} | Effective Fracture toughness |
| K_{leac} | Environment-assisted cracking threshold toughness |
| MEOP | Maximum Expected Operating Pressure |
| MIL | Military |
| MRB | Material Review Board |
| MS | Margin of Safety |
| NDE/NDI | Nondestructive Evaluation/Nondestructive Inspection |
| POD | Probability of Detection |
| SRM | Solid Rocket Motor |
| SRMC | Solid Rocket Motor Case |
| VDT | Visual Damage Threshold |

4. GENERAL REQUIREMENTS

This section presents the general requirements for the design, analysis, materials selection and characterization, manufacturing and process, quality assurance, operation and maintenance for the SRMCs manufactured with metals or composites.

4.1 General Design and Analysis

The general design, analysis and analysis requirements for SRMCs are delineated in the following sections.

4.1.1 System Analysis

A thorough systems analysis of the SRM shall be used to establish the MEOP. The effect of each of the other component operating parameters on the MEOP shall be determined; failure tolerance requirements shall be considered. External loads and temperature shall be evaluated for the entire service life of the hardware.

For CSRMCS, a system impact threat analysis shall be conducted to provide information for the impact damage control plan. The impact threat analysis shall document the conditions (source and magnitude of impact threat at various stages of operations) under which damage can occur.

4.1.2 Loads, Pressures, and Environments

The anticipated loads, pressures and associated temperatures throughout the service life of the SRMC shall be used to define the design load/pressure/temperature profile. Conditions considered shall include acceptance hydrostatic proof test, ground handling, propellant loading, transportation, storage, integration to the launch system core vehicle and launch.

4.1.3 Strength

All SRMCs shall sustain the specified proof pressure during a hydro-proof test without detrimental deformation in metallic components or visible fiber breakage in composites. The minimum hydro-proof pressure shall be 1.1 x MEOP. In addition, for CSRMCS, the proof pressure shall not exceed 85% of average ultimate strength of the composite case as determined by full-scale burst tests. All SRMCs shall sustain a minimum design burst pressure of 1.25 x MEOP in the qualification burst tests without collapse or rupture. SRMCs shall be designed to preclude failure in the joints under ultimate load. Degradation of material properties due to the effects of temperature and humidity shall be accounted for in the design of SRMCs, including their mechanically fastened and adhesively bonded joints.

When the hydro-proof tests and qualification burst tests are conducted at temperature and humidity conditions other than the worst-case design temperature, the change in material properties at the test conditions shall be accounted for in the proof pressure and design burst pressure. The test configuration shall simulate structural interfaces between the SRMC and the rest of the vehicle, and the ground attachments, if any, in order to replicate launch and flight external load distributions.

4.1.4 Field Joint Sealing

All SRM field joints shall be provided with redundant integration seals consisting of O-rings or other elastomeric seals. A single O-ring shall be capable of retaining the maximum operating and SRMC acceptance proof test and qualification test pressures. The factory and field joints shall be protected from corrosive environment.

4.1.5 Stiffness

All SRMCs shall possess adequate stiffness to preclude detrimental deformation at limit load and MEOP in the expected operating environments throughout their respective service lives. In addition, SRMC stiffness shall be consistent with the minimum required to ensure stable elastic behavior of the vehicle, structural adequacy under transient dynamic loads, and the body-bending frequencies to within the limits imposed by the vehicle flight control system. SRMC stiffness shall be controlled by the proper selection of its thickness and/or material.

4.1.6 Thermal Effects

Thermal effects, including temperatures, thermal gradient, thermal stresses and deformations, as well as changes in the physical and mechanical properties of the materials of construction, shall be considered in the design of SRMCs. These effects shall be based on temperature extremes predicted for the operating environment plus design margins.

4.1.7 Structural Analysis

4.1.7.1 Stress Analysis

A stress analysis of an SRMC design shall be conducted with the assumption that no crack-like flaws exist in the metal case and other metallic components. For CSRMCS, it shall be assumed that no impact damage exists in the composite cases and other composite elements. The analysis shall determine stresses resulting from the combined effects of internal pressure and flight loads. Both membrane stresses and bending stresses resulting from internal pressure and external loads shall be calculated.

Finite element or other proven structural analysis techniques shall be used to perform the stress analysis. For CSRMCS, effects of winding angles, winding sequences, and geometrical discontinuities shall be assessed. The analysis shall address ply-by-ply stress response to applied pressure and loads and environments to determine minimum margins of safety for each applicable failure mode, such as fiber fracture, in-plane shear failure, and delaminations. The CSRMCS shall be designed such that fiber fracture will initiate the structural failure. Failure at joints and transition regions requiring complex interactions among various failure modes shall be precluded.

The analysis tools used for the structural assessment shall be correlated against past test results to demonstrate the accuracy of the methodology. The analytical tool verification shall be submitted as part of the stress analysis report.

The margin of safety calculated by using appropriate material allowables shall be positive for all loading conditions. Unless otherwise specified, "A" basis allowable shall be used in the margin of safety calculations.

4.1.7.2 Field Joint Deformation Analysis

An analysis shall be conducted to determine SRMC field joint deformations for the use in the joint seal design. The analysis shall consider all loading conditions during motor operation and determine the maximum possible joint deformation. Deflection predictions shall be verified by full-scale test measurements.

4.1.8 Damage Tolerance (Safe-Life)

For a metallic SRMC, or for the fracture critical metallic components of a CSRM C such as the metal joints, damage tolerance ability shall be demonstrated by analysis or test in order to prevent premature failure due to the existence of cracks or crack-like defects. The crack size considered shall be the statistical values of the detectability of the NDE methods used in the acceptance test program, i.e., 90% probability of detection (POD) at a 95% confidence level.

4.1.9 Impact Damage Control

All CSRM Cs shall be placed under impact damage control. Impact damage that may degrade the structural performance of the CSRM Cs below requirements specified herein shall be prevented.

For impact damage mitigation, one or more of the following approaches shall be adapted:

- a. Approach A: Using impact damage protection and indicators
- b. Approach B: Demonstrating impact damage tolerance abilities by testing

4.1.9.1 Impact Damage Control Plan

An impact damage control plan shall be prepared for a new CSRM C design when required. System impact threat analysis specified in 4.1.1 shall be used to establish the procedures that mitigate these threats. Appropriate NDE technique(s) used to detect impact damage at various stages including manufacturing, testing, shipment and assembly shall be delineated. The selected impact damage tolerance demonstration approach shall be specified in the impact damage control plan.

4.1.9.2 Approach A: Impact Damage Protection/Indication

When this approach is adapted, the following requirements shall apply.

4.1.9.2.1 Protective Covers

Impact damage protection covers shall provide isolation from a potential impact damage event. The effectiveness of protective covers shall be demonstrated by test. The protective cover shall be designed to completely protect the CSRM C under the worst credible impact threat defined in the impact damage control plan. Protective covers shall not be removed until the latest feasible time prior to launch.

4.1.9.2.2 Indicators

The effectiveness of the indicators to provide positive evidence of an impact damage event shall be demonstrated by test.

4.1.9.3 Approach B: Impact Damage Tolerance Demonstration

Test is the only acceptable method for demonstrating impact damage tolerance capabilities of a new CSRMC design. Full-scale or subscale cases with full diameter and thickness shall be used as test specimens. The impact damage shall be induced in the most critical condition (e.g., loaded with propellant vs. empty case) and location(s). The minimum impact energy level shall be the worst-case threat or the NDE threshold, whichever is greater.

After inducing impact damage to the test articles, verification of the capability to satisfy the strength requirement of Section 4.1.3 shall be demonstrated by burst test.

Impact damage tolerance demonstration by analysis in lieu of test is acceptable for a derivative of the CSRMC design that has impact damage tolerance demonstration test data.

4.1.10 Stress-Rupture Life

For CSRMCS, there shall be no credible stress-rupture failure mode for the composite materials based on stress rupture life data for a probability of survival value. Unless otherwise specified, the minimum probability of survival shall be 0.999.

4.2 Materials

4.2.1 Metallic Materials

4.2.1.1 Metallic Material Selection

Material selection for metallic components of an SRMC shall be based on known material strengths, consistent with the overall program requirements.

For fracture-critical metallic components, fracture properties shall be accounted for in material selection. The fracture toughness shall be as high as practicable within the context of structural efficiency and fracture resistance. Materials that have K_{Ieac} less than 60% of the plane strain K_{Ic} in the expected operating environments shall not be used, unless it can be shown by worst case fracture mechanics analysis that the lower K_{Ieac} will not cause structural failure.

4.2.1.2 Metallic Material Evaluation

Candidate materials shall be evaluated with respect to material processing, fabrication methods, manufacturing operations, refurbishment procedures and processes, and other factors that affect the resulting strength and fracture properties of the material in the fabricated as well as the refurbished configurations.

The evaluation shall ascertain that the mechanical properties, strengths, and fracture properties used in design and analyses will be realized in the actual hardware and that these properties are compatible with the expected operating environments. Materials that are susceptible to stress-corrosion cracking or embrittlement mechanisms, such as hydrogen embrittlement, shall not be used.

4.2.1.3 Metallic Material Characterization

The allowable mechanical properties and fracture properties of all metallic materials selected shall be characterized in sufficient detail to permit reliable and high-confidence predictions of their structural

performance in the expected operating environments unless these properties are available from reliable sources, such as MIL-HDBK-5, Damage Tolerance Design Handbook, Aerospace Structural Metals Handbook, or other sources. Where material properties are not available, they shall be characterized by tests. The material characterization test program shall produce the following strength and fracture properties for the parent metals, weld-joints, and heat-affected zones as a function of the expected operating environments, including proof test environments as appropriate:

- a. Tensile yield strength, F_{ty} , and ultimate tensile strength, F_{tu} ;
- b. Plane strain fracture toughness, K_{Ic} , effective fracture toughness, K_{Ie} , and stress-corrosion cracking threshold toughness, K_{Ieac} ; and
- c. Fatigue crack growth rates, da/dN

Uniform test procedures shall be employed for determining material fracture properties as required. These procedures shall conform to recognized standards (Refs. ASTM E399, ASTM E647, and ASTM E1681), or approved alternate methods. The test specimens and procedures utilized shall provide valid test data for the intended application.

A minimum of 3 tests shall be conducted to determine nominal value of each of the properties, including fracture toughness, fatigue crack growth rate data corresponding to each alloy system, temper, product form, thermal/chemical environments and loading spectra can be established to evaluate compliance with safe-life requirements.

4.2.1.4 Metallic Material Strength Allowables

For metallic materials used in SRMCs, the A-basis strength values determined per 4.2.1.3 shall be used. Effects of the operating environments shall be accounted for in strength allowables.

4.2.2 Composite Materials

4.2.2.1 Composite Material Selection

Composite material systems used for CSRMCs shall be selected on the basis of environmental compatibility, material strength/modulus, and stress rupture properties. The effects of fabrication process, sizing, temperature/humidity, load spectra, and other environmental conditions that may affect the strength and stiffness of the material in the fabricated configuration shall also be included in the rationale for selecting the composite material system.

4.2.2.2 Composite Materials Evaluation

The composite materials selected for building the shell shall be evaluated with respect to the material processing, fabrication methods, manufacturing operations, refurbishment procedures and processes, operating environments and other pertinent factors that affect the resulting strength and stiffness properties of the material in the fabricated as well as refurbished configurations. Unless the properties are available from reliable sources such as those given in the references, the properties of the composite materials selected shall be characterized for all failure modes in sufficient detail to permit reliable and high confidence predictions of the structural performance in their expected operating environments. The supporting data shall provide justification for the declared properties consistent with the operating and non-operating environments.

4.2.2.3 Composite Material Characterization

Uniform test procedures shall be employed for determining material properties as required. The test specimens and procedures utilized shall provide valid test data for the intended application.

4.2.2.4 Composite Material Strength Allowables

For composite materials used in CSRM, the “A” basis strength allowables shall be used. “A” basis allowables shall be determined from burst testing using rings, sub-scale or full-scale motor cases. Strand data can only be used to establish variability in the yarn strength and modulus. When data are used from coupons or sub-scale cases, analysis of test data shall demonstrate its relevance to full-scale cases. A-basis strength allowables for composite joints shall be determined from test coupons representative of full-scale joints. CSRM and their joint strength allowables shall account for degradation due to the effects of temperature and humidity.

4.3 Fabrication and Process Control

The design of all SRMCs shall employ proven manufacturing processes and procedures to the greatest possible extent. In the event new processes are developed, they shall be verified on pathfinder units prior to their implementation in the production of test and of flight hardware.

4.3.1 Metal Parts Fabrication and Process Control

Proven processes and procedures for fabrication and repair of the metallic SRMC, or the metal parts of the CSRM, shall be used to preclude damage or material degradation during material processing, manufacturing operations, and refurbishment. In particular, special attention shall be given to ascertain that the thermal treatment, machining, drilling, grinding and repair operations are within the state of the art and have been used on similar hardware. Fracture toughness and mechanical and physical properties shall be within established design limits after exposure to the intended fabrication processes. Fracture control requirements and procedures shall be defined in applicable drawings and process specifications. Detailed fabrication instructions and controls shall be provided to ensure proper implementation of the fracture control requirements.

4.3.2 Composite Parts Fabrication and Process Control

The composite fabrication process shall be a controlled documented process. Incorporated materials shall have certification demonstrating acceptable variable ranges to ensure repeatable and reliable performance. The fabrication process shall control or eliminate detrimental conditions in the fabricated article.

An inspection plan shall be developed per 4.4.1 to identify all critical parameters essential for verification. In-process inspection or process monitoring shall be used to verify the setup, and the acceptability of critical parameters during the filament winding or prepreg laying-up process.

The amount of each incorporated composite material on the article from the composite fabrication shall be verified.

4.4 Quality Assurance

A quality assurance program, based on a comprehensive study of the product and engineering requirements, shall be established to ensure that the necessary NDE and acceptance tests are performed effectively to verify that the product meets the requirements of this document. The program shall ensure that no damage or degradation has occurred during material processing, fabrication, inspection, acceptance tests, propellant loading, shipping, storage, launch pad assembly, or operational use and refurbishment; and that defects that could cause failure are detected or evaluated and corrected. As a minimum, the following shall be included in the quality assurance program.

4.4.1 Inspection Plan

An inspection master plan shall be established prior to start of fabrication. The plan shall specify appropriate inspection points and inspection techniques for use throughout the program, beginning with material procurement and continuing through fabrication, assembly, acceptance-proof test, propellant loading, shipment and operation, as appropriate. In establishing inspection points and inspection techniques, consideration shall be given to material characteristics, fabrication processes, design concepts, corrosion control, and accessibility for inspection of defects.

4.4.1.1 Inspection Techniques

The inspection techniques selected for metallic components shall have the capability to determine the size, geometry, location and orientation of a crack. Magnetic particle and/or eddy current shall be used for detecting cracks. Other NDE techniques used shall have demonstrated 90% probability of detection (POD) at a 95% confidence level.

For composite materials, visual inspection shall be performed in conjunction with inspection with state-of-the-art NDE techniques. Ultrasound, mechanical impedance analyzer, thermography and shearography are the NDE techniques that can be selected. Acoustic emission is a potential technique that may be used during the hydro-proof test.

4.4.1.2 Inspection Data

Inspection data shall be maintained throughout the service life of an SRMC. These data shall be reviewed periodically and assessed to evaluate trends and anomalies associated with the inspection procedures, equipment and personnel, material characteristics, fabrication processes, design concept and structural configuration. The result of this assessment shall form the basis of any required corrective action.

4.4.2 Acceptance Test

Acceptance tests shall be conducted on every SRMC to verify workmanship. Accept/reject criteria shall be formulated prior to tests. The test fixtures shall be designed to permit application of hydro-proof pressure without jeopardizing the flightworthiness of the hardware. As a minimum, the following tests are required:

- a. Pre and post proof NDE
- b. Leak check
- c. Hydro-proof testing

4.4.2.1 NDE

Every SRMC shall be subjected to visual inspection and NDE before and after proof test per the inspection plan of 4.4.1

4.4.2.2 Hydro-Proof Test

Each SRMC shall be hydro-proof tested. The minimum proof pressure shall be $1.1 \times \text{MEOP}$. Proof test above certain pressure and load levels appears to cause severe damage to composites—such as fiber breakage, interface debonding, delamination, and matrix cracking that cannot be adequately detected by the presently available techniques. The proof pressure for a CSRM C should not exceed 0.85 of its average ultimate strength, as test pressure above that critical level may induce premature failure.

Unless otherwise specified, the duration of the proof test shall simulate the flight profile. The SRMC shall not leak, rupture, or experience damage during acceptance testing. The Externally applied flight loads and boundary conditions to SRMCs shall be properly simulated. In the event it is not practical, the test pressure can be increased accordingly to account for the external loads and boundary condition effects. The acceptance proof test shall be performed at ambient temperatures and humidity conditions unless the specific design conditions dictate otherwise. If the strength of the CSRM C is lower at the maximum use conditions, then the proof test pressure shall be increased to account for the effects of the flight environments on the mechanical strengths demonstrated by coupon tests.

4.4.2.3 Leak Check

Every SRMC shall be subject to leak checks before and after hydro-proof testing. In any event, leak check pressure shall not exceed the MEOP. The temperature of the test fluid in the SRMC shall be monitored during fill to ensure that safe operational limits are not exceeded. Both the metallic end fittings (if present) and composite shall be monitored. The maximum and minimum temperature experienced by these elements during leak test shall be recorded.

The leak check shall be conducted using a certified and calibrated system. System calibration is in addition to sensor instrumentation calibration. Calibration shall be done at a minimum of one decade below the maximum specified leak rate for the case.

All solid rocket motor field joints' primary seals shall be leak checked. The field joints shall be pressurized with a mixture of helium and nitrogen gas. Leakage rates shall be recorded and be within acceptable limits.

4.5 Repair and Refurbishment

When inspections reveal structural damage or defects exceeding the permissible levels, the damaged hardware shall be assessed by the material review board (MRB) for repair, refurbishment, or replacement. All repaired or refurbished hardware shall be re-certified after each repair and refurbishment by the applicable acceptance test procedure for new hardware to verify its structural integrity and to establish suitability for continued service.

4.6 Storage

During storage, SRMCs shall be protected against exposure to adverse environments (e.g., temperature, humidity) that could cause corrosion or other forms of material degradation. In addition, they shall be protected against impact damage. Induced stresses due to storage fixture constraints shall be minimized by suitable storage fixture design.

4.7 Transportation

SRMCs shall be protected against damage from the transportation environment and physical sources such as physical impact. Critical environments, such as temperature and humidity extremes, excessive vibration, and shock during transportation, shall be recorded using proper instrumentation.

5. DESIGN VERIFICATION REQUIREMENTS

Design verification requirements for all SRMCs include margin of safety demonstration, damage tolerance (safe-life) and impact damage control verification, and qualification testing, including pressure cycling testing, leak check, and burst test.

5.1 Margin of Safety (MS)

The SRMC shall have a positive margin of safety under combined pressure, loads and accompanying environments for each design condition, including ground handling, transportation, pre-launch, lift-off, ascent, and separation. The SRMC shall not experience yielding or detrimental deformation under each design limit and acceptance proof test conditions. The ultimate loads used in margin of safety analysis shall be determined by a rational combination of pressure, loads, and accompanying environment in accordance with the following equation:

$$\text{Ultimate Load} = K_1 L_P + K_2 L_L + K_3 L_T$$

Where $K_1 = 1.25$ (minimum) when the term is additive to the algebraic sum, ΣL

$K_1 = 1.0$ when the term is subtractive to the algebraic sum, ΣL

$K_2 = 1.25$ (minimum) when the term is additive to the algebraic sum, ΣL

$K_2 = 1.0$ when the term is subtractive to the algebraic sum, ΣL

$K_3 = 1.25$ (minimum) when the term is additive to the algebraic sum, ΣL

$K_3 = 1.0$ when the term is subtractive to the algebraic sum, ΣL

L_P = Maximum expected operating pressure

L_L = Design limit load

L_T = Loads induced by temperature and humidity environments

5.2 Damage Tolerance (Safe-Life) Demonstration

For the fracture critical metallic components of an SRMC, damage tolerance (safe-life) demonstration requirements specified in 4.1.8 shall be met. The demonstration shall be done by either fracture mechanics safe-life analysis or test.

5.2.1 Damage Tolerance (Safe-Life) Analysis

If fracture mechanics crack growth analysis is employed for damage tolerance (safe-life) demonstration, state-of-the-art crack growth software or other proven equivalent fracture mechanics crack growth analysis hand calculation methodology shall be used to conduct the damage tolerance (safe-life) analysis. Undetected cracks shall be assumed to be in critical locations and in the most unfavorable orientation with respect to the applied stress and material properties. The assumed size of the cracks shall be based on the appropriate NDE technique(s). Corner cracks with the flaw shape a/c in the range of 0.2 to 1 shall be considered in the holes and surface cracks with the flaw shape $a/2c$ in the range of 0.1 to 0.5 shall be considered for other regions. Nominal values of fracture toughness and fatigue crack-growth-rate data shall be used in the analysis. A life-factor of 4 shall be applied in damage tolerance (safe-life) analysis.

5.2.2 Damage Tolerance (Safe-Life) Test

Damage tolerance (safe-life) testing is an acceptable alternative to demonstrating damage tolerance (safe-life) by analysis. Crack(s) shall be manufactured in the worst locations and in the most

unfavorable orientation with the applied loads and material properties. A life-factor of 4 shall be applied in the test results.

5.3 Impact Damage Tolerance Demonstration

For the CSRM C and other critical composite components, impact damage tolerance demonstration requirements specified in 4.1.9.3 shall be met. The demonstration shall be done by test only.

5.4 Qualification Test

The required minimum number of test articles for qualification testing is four. If there is a development test program, the qualification tests shall be conducted on a minimum of two flight-like articles. Table 5-1 shows the corresponding pressure requirements for each test article. The qualification test procedure shall be approved by the procurement agency prior to the start of qualification testing.

As a minimum, the following tests shall be conducted on all new or substantially modified SRMCs:

- a. Acceptance test per 4.4.2
- b. Pressure cycle testing per 5.4.1
- c. Burst testing per 5.4.2

When conducting qualification testing, the test fixtures, support structures, and methods of environmental application shall induce representative boundary conditions for the intended application. The types of instrumentation for measuring strains and displacements and their locations in qualification tests shall be based on the results of the stress analysis in 4.1.7 and 5.1. Additional instrumentation shall be installed to provide complete monitoring and control of the test fixtures and hardware, including temperature, pressure, and other critical parameters. The instrumentation and test plan shall be formulated to provide sufficient data to ensure proper application of input loads, pressures, environments, and vessel responses to allow assessment against accept/reject criteria, which shall be established prior to test. The sequences, combinations, levels, and duration of loads, pressure, and environments shall demonstrate that design requirements have been met. The test temperature shall be consistent with the critical-use temperature, or test pressures shall be adjusted to account for the worst-case temperature effects on material properties.

5.4.1 Pressure Cycle Test

Pressure cycling testing on SRMCs shall be performed on one test article according to Table 5-1. The test fluid used for pressure cycling test shall be the same as used in the hydro-proof testing.

The requirement for application of external loads in combination with internal pressures during testing shall be evaluated based on the relative magnitude and/or destabilizing effect of stresses due to the external loads. If limit-combined tensile stresses are enveloped by the test pressure stress, the application of external loads may not be required. If the application of external loads is required, the load shall be cycled to limit load level for four times the predicted number of cycles of the most severe design condition (e.g., destabilizing load with constant minimum internal pressure or maximum additive load with a constant MEOP).

Table 5-1. Qualification Test Pressure Cycle Requirements

| Test Item | Pressure Cycle Test | Burst Test⁽¹⁾ |
|---------------------------|----------------------------|---------------------------------|
| Case # 1 | N/A | DBF x MEOP |
| Case # 2-3 ⁽²⁾ | N/A | DBF x MEOP |
| Case #4 | 4 service-life cycles | DBF x MEOP |

Note: (1) After demonstrating no burst at the design burst pressure test level, increase pressure to actual burst of vessel. Record actual burst pressure.

(2) Test cases #2-3 may be deleted if two or more burst tests have been conducted in design development test program and the results have been used in determining the allowable.

5.4.2 Burst Test

Burst testing shall be conducted to verify compliance to the design burst factor requirement established by this standard. The case shall be pressurized to the design burst pressure level, i.e., pressure equal to DBF x MEOP. Unless otherwise specified, the minimum design burst strength shall be 1.25 x MEOP. The test pressure shall be held at the design burst pressure for 5 seconds minimum. The case shall not burst or prior to the end of the hold time. Upon successful completion of the hold period, the pressure shall be increased at a controlled rate until case burst.

SMC Standard Improvement Proposal

INSTRUCTIONS

1. Complete blocks 1 through 7. All blocks must be completed.
2. Send to the Preparing Activity specified in block 8.

NOTE: Do not be used to request copies of documents, or to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements. Comments submitted on this form do not constitute a commitment by the Preparing Activity to implement the suggestion; the Preparing Authority will coordinate a review of the comment and provide disposition to the comment submitter specified in Block 6.

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|---|--|-------------------------|
| SMC STANDARD CHANGE RECOMMENDATION: | 1. Document Number | 2. Document Date |
| 3. Document Title | | |
| 4. Nature of Change (Identify paragraph number; include proposed revision language and supporting data. Attach extra sheets as needed.) | | |
| 5. Reason for Recommendation | | |
| 6. Submitter Information | | |
| a. Name | b. Organization | |
| c. Address | d. Telephone | |
| e. E-mail address | 7. Date Submitted | |
| 8. Preparing Activity | Space and Missile Systems Center AIR FORCE SPACE COMMAND 483 N. Aviation Blvd. El Segundo, CA 91245 Attention: SMC/EAE | |